Development of Specifications for the Use of an Uncalibrated Echo Sounder to Estimate Populations of Small Limnetic Fish

T. W. Gjernes, K. D. Hyatt and D. P. Rankin

Department of Fisheries and Oceans
Fisheries Research Branch
Pacific Biological Station
Nanaimo, British Columbia V9R 5K6

December 1986

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1509

87-01519/

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1–456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457–714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715–924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences No. 1509

December 1986

DEVELOPMENT OF SPECIFICATIONS FOR THE USE OF AN UNCALIBRATED ECHO SOUNDER TO ESTIMATE POPULATIONS OF SMALL LIMNETIC FISH

by

T. W. Gjernes, K. D. Hyatt and D. P. Rankin

Department of Fisheries and Oceans
Fisheries Research Branch
Pacific Biological Station
Nanaimo, British Columbia V9R 5K6

(c)Minister of Supply and Services Canada 1986

Cat. No. Fs 97-97-6/1509E ISSN 0706-6457

Correct citation for this publication:

Gjernes, T. W., K. D. Hyatt and D. P. Rankin. 1986. Development of specifications for the use of an uncalibrated echo sounder to estimate populations of small limnetic fish. Can. Tech. Rep. Fish. Aquat. Sci. 1509: 35 p.

ABSTRACT

Gjernes, T. W., K. D. Hyatt and D. P. Rankin. 1986. Development of specifications for the use of an uncalibrated echo sounder to estimate populations of small limnetic fish. Can. Tech. Rep. Fish. Aquat. Sci. 1509: 35 p.

Assessment of sockeye stock responses to fertilization of British Columbia coastal lakes has been ongoing since initiation of an expanded Lake Fertilization Program under the auspices of a joint federal-provincial Salmonid Enhancement Program in 1976. Hydroacoustic and midwater trawling techniques have been under continuous development in association with this program to census limnetic populations of fish in up to 25 coastal lakes annually. High performance, portable echosounders designed specifically for census of fish populations have only been readily available from commercial sources during the latter years of this work. Census work in the early years of the program depended on the use of an inexpensive, 200 kHz, Furuno echosounder (model FM22) equipped with a customized time-varied-gain (TVG) circuit. Prior to routine use in census of limnetic fish populations, field trials were conducted with the modified FM22 to specify its operating characteristics for detection of acoustic targets represented by fish of approximately 50-70 mm in size. Results indicate that the modified FM22 maintains an effective beam angle of 7.6° to depths up to 60 m. Results from execution of several surveys involving simultaneous use of a Simrad EY-M echosounder, specifically designed for quantitative census of fish populations, and the FM22 confirm that the operating characteristics of the modified FM22 are reliable enough in combination with the precise specifications outlined here to be used interchangeably with the EY-M to routinely census limnetic fish populations. Advantages and disadvantages of the hardware and procedures developed for census of limnetic fish populations in these studies are discussed.

RESUME

Gjernes, T. W., K. D. Hyatt and D. P. Rankin. 1986. Development of specifications for the use of an uncalibrated echo sounder to estimate populations of small limnetic fish. Can. Tech. Rep. Fish. Aquat. Sci. 1509: 35 p.

Depuis le lancement, en 1976, d'un Programme élargi de fertilisation de lacs sous les auspices du Programme fédéral-provincial de mise en valeur des salmonidés, le comportement des saumons rouges face à la fertilisation des lacs côtiers de la Colombie-Britannique a fait l'objet d'une évaluation continue. Dans le cadre de ce programme, on a mis au point des techniques hydroacoustiques et de chalutage mésopélagique pour dénombrer les populations limnicoles de poissons dans au moins 25 lacs côtiers par année. Ce n'est qu'au cours des dernières années qu'on a facilement pu obtenir sur le marché des échosondeurs portatifs à performance élevée conçu expressément pour le dénombrement des populations de poissons. Au cours des premières années du programme, les relevés démographiques étaient effectués avec un échosondeur bon marché Furuno de 200 kHz (modèle FM22) équipé d'un circuit d'amplification chronomodulé particulier. Avant l'utilisation courante pour le dénombrement des populations limnicoles de poissons, on a effectué des essais sur le terrain avec le FM22 modifié afin de déterminer son mode de fonctionnement pour la détection de cibles acoustiques constituées de poissons d'environ 50-70 mm de longueur. Les résultats révèlent que le FM22 modifié maintient un angle de rayon de 7,6° efficace jusqu'à des profondeurs de 60 m. Les résultats obtenus au cours de plusieurs relevés portant sur l'utilisation simultanée d'un échosondeur Simrad EY-M, conçu expressément pour le dénombrement de populations de poissons, et le FM22 ont confirmé que le mode de fonctionnement de ce dernier est assez fiable quand on le combine avec les caractéristiques précisées dans le présent document. Le FM22 peut donc être utilisé alternativement avec le EY-M pour le dénombrement courant de populations limnicoles de poissons. On indique aussi les avantages et inconvénients du matériel et des méthodes élaborées pour le dénombrement de ces populations dans le cadre de ces études.

INTRODUCTION

In the last 10-15 years, hydroacoustic techniques have been developed for enumeration of limnetic populations of juvenile sockeye salmon (Oncorhynchus nerka) (Nunnallee 1980). These techniques, to a large extent, have been successful because the nocturnal distribution of young sockeye makes them particularly suitable for enumeration and sampling by hydroacoustic and midwater trawl surveys (Narver 1970; Nunnallee 1980; Robinson and Barraclough 1978; Woodey 1972). The methods described in the literature require the use of a boat $\geq$ 5m in length (Nunnallee et al. 1973; Robinson and Barraclough 1978). Consequently, the techniques are generally used in lakes with road access.

As part of a Federal-Provincial salmonid enhancement project, several lakes in coastal British Columbia have been artificially enriched to increase production of sockeye salmon (Stockner and Hyatt 1984). The effect of inorganic nutrient addition on primary and secondary production and subsequently on growth and survival of sockeye are under study in order to assess the degree to which runs of salmon may be enhanced by the fertilization program (Hyatt et al. 1984; Hyatt and Stockner 1985). Estimates of limnetic sockeye abundance are needed to provide a basis for estimating survival and production rates. Many lakes under study are accessible only by float-equipped aircraft. Therefore, a hydroacoustic and midwater-trawl survey system that uses relatively lightweight and portable equipment was developed. The trawling system has been described previously (Gjernes 1979) while Hyatt et al. (1984) have documented the standard procedures used to conduct hydroacoustic and trawl surveys in the field. In 1977, at the time our survey work was first initiated, we searched for an echosounder that would readily satisfy our special requirements for census of fish populations in the limnetic zone of small, remote lakes. The ideal sounder had to be small, lightweight, highly portable, and adaptable to a 12 volt battery power source. Reliable operation under exposure to extremes of temperature and humidity in small open boats was essential. Further, the sounder had to have a precisely specified acoustic beam configuration and a time varied gain to compensate for loss of acoustic signal strength over depths to at least 50 m. At that time no commercially available hardware was found to satisfy these requirements.

The hardware that came closest to satisfying our requirements was an inexpensive commercial sounder (Furuno model FM22) for which a customized time-varied-gain (TVG) circuit had recently been developed[1]. We acquired one of these customized sounders and all census work conducted by us on limnetic fish populations between 1977 and 1981 was based on use of the modified FM22. By 1982, the juvenile sockeye survey work undertaken by the Fish Ecology Unit (FEU) of the Lake Enrichment Program (LEP) had increased to the point where a second echosounder was required. Consequently we purchased a Simrad EY-M echosounder especially developed for quantitative measurement of fish

---

[1]The TVG circuit was developed by staff of the Technical Services Division of the Support Services Branch, Canada Department of Fisheries and Oceans (P. Ryan pers. comm.)

populations in fresh water (Anonymous 1979). Since 1982 both the Simrad EY-M and the FM22 have been used interchangeably in our census work.

In this report we first document procedures carried out to specify the operating characteristics of the FM22 echosounder such that it could be used to routinely census populations of small limnetic fish. Our second objective is to provide results from cross-calibration trials conducted using both the EY-M and FM22. Since the former sounder has been specifically designed for quantitative measurement of fish populations these results may be considered as an independent assessment of the relative reliability of census results obtained with the FM22 sounder when operated according to specifications developed by us.

MATERIALS AND METHODS

DEVELOPMENT OF FM22 SPECIFICATIONS TO CENSUS FISH

The Furuno FM22 echosounder has an operating frequency of 200 kHz with an output of approximately 100 W and a pulse width of 1.0 ms. Pulse rate of the echosounder can be set at 112 or 224•min^{-1}. Echos are recorded on a dry paper echogram. The 40 log r (depth) time-varied-gain (TVG) circuit incorporated into the echosounder corrects for two-way spreading loss of signal strength[2]. The TVG operates for 64 ms which corresponds to a depth of approximately 46 m in fresh water (sound speed of approximately 1450 m•s^{-1} at 10°C). Beyond 46 m sensitivity of the echosounder decreases at a rate of 40 log r•46^{-1}. During our surveys the sounder was set at maximum gain which was 5 steps above the lowest setting at which sockeye of fork length 50-60 mm were detected on the echogram. Each gain step is 5.5 dB, therefore, gain was 27.5 dB plus an unknown amount (0-5.5 dB) above the minimum detection limit of acoustic targets produced by the average sized fish we wished to census.

Hyatt et al. (1984) and Hyatt and Stockner (1985) should be consulted for detailed accounts of the gear and techniques used generally on acoustic and trawl surveys to census limnetic fish. Of relevance here, the echosounder's transducer was mounted on a simple towing sled made of 4.7 mm aluminum plate (Fig. 1) and lashed into position alongside a 4-m-long inflatable boat. The bridle of the towing sled was adjusted to maintain a perpendicular acoustic axis. A survey at a given lake and date consisted of executing a series of echo-sounding transects across the lake. Transect locations were selected such that each basin or arm of the lake was represented by at least one transect and the total lineal distance sounded on transects was roughly proportional to lake area (Hyatt and Stockner 1985).

---

[2]Signal strength also decreases as a result of sound absorbtion in the water. In freshwater at 10°C and a frequency of 200 KHz absorbtion is approximately 1 dB•100 m^{-1}. Therefore at a depth of 50 m signal reduction is only 1 dB (2-way) and has been ignored in this report.

There are two basic techniques for estimating fish abundance via hydroacoustic surveys: echo integration and echo counting. Echo integration entails summing the squared voltage response of the echo sounder during a survey and dividing the summed voltage by the average squared voltage response from a single fish (or unit biomass of fish) to provide an estimate of abundance or biomass. Echo counting consists of counting the echo returns and treating each as a response from an individual fish. Here the echos are represented by traces on an echogram. The number of echo traces divided by the sample volume provides an estimate of fish concentration per unit volume. Thorne (1983a) provides a good description of the techniques used for making population estimates and of the problems associated with echo integration and echo counting. Kieser and Mulligan (1984) may be consulted for a detailed treatment of analytical considerations associated with use of echo counting data. Survey procedures adopted in the present study were designed to obtain echograms from which population estimates could be made on the basis of echo trace counting.

Acoustic surveys were conducted at night, generally during nautical twilight[3], due to diel changes in the vertical distribution of young sockeye which permit their discrimination as separate targets only on echograms obtained under nocturnal conditions. A number of authors (Narver 1970, Woodey 1972; Eggers 1975; and Nunnallee 1980) have described these changes as follows. From early summer through autumn, limnetic sockeye are commonly found at considerable depth during daylight hours in tightly packed schools such that individual targets cannot be identified on echograms. However as dusk approaches young sockeye migrate en masse towards the lake surface and their schools disperse as light levels become too low for fish to maintain visual contact. Echogram records obtained during this interval (see Woodey 1972; Eggers 1975; Johnson and Burczynski 1985 for examples) commonly demonstrate a shift from the characteristic acoustic traces associated with fish schools (clusters of densely packed targets clumped within one or two narrow depth intervals) to those associated with individual fish (an abundance of well defined individual targets dispersed throughout a relatively broad depth range).

FM22 ACOUSTIC-BEAM WIDTH DETERMINATIONS

The parameters required for estimation of fish abundance via echo counting are number of targets detected, volume of water sampled, and total volume of water in which the population is located. Sample volume is a function of depth, distance travelled and beam width of the echo sounder. Beam width of an echo-sounder transducer is usually described as the angle at which one-way power or sensitivity is decreased by 50% (-3 dB points). However, the angle over which a fish will be detected depends on system gain and on fish size (target strength) as well as transducer characteristics. Therefore, in this paper the angle (cone) within which targets of interest are detected will be referred to as effective beam width (EBW).

---

[3]The period when the sun is at least 12° below the horizon

In most published reports where the abundance of juvenile sockeye has been estimated via hydroacoustic surveys, EBW of the echo sounder has been calculated by the duration-in-beam technique (Nunnallee 1974; Robinson and Barraclough 1978; Thorne 1980). Employment of this technique requires the use of an oscilloscope and an accurate device to measure boat speed. Generally the acoustic data are also recorded on magnetic tape for analysis under more favourable conditions. Use of an oscilloscope was not practical in the small inflatable boats used here nor could data be recorded on magnetic tape because the FM22 echo sounder lacked a suitable output. Therefore, techniques that did not require an oscilloscope or a tape recorder were developed to measure the EBW of the FM22.

BEAM WIDTH AT DEPTHS LESS THAN 30 m

The EBW was estimated by measuring the relationship between depth and the distance from the acoustic axis of the transducer at which a target could first be detected (Fig. 2). The targets used were tournament quality ping pong balls. These have a target strength of -41 to -43 dB (Welsby and Hudson 1972; Traynor and Ehrenberg 1979). Juvenile sockeye 60 mm in fork length should have an average dorsal-aspect, target strength at 200KHz of -47 to -49dB according to Love (1971) and McCartney and Stubbs (1971). Actual average in situ target strength of the fish may differ from the above estimate by 2-3 dB but for this work a value of -48dB was assumed. Measurements were conducted with the echo sounder set one gain step (5.5dB) lower than that used during hydroacoustic surveys. Therefore, the measured beam width should apply to fish with a target strength 5.5dB lower than a ping pong ball (i.e. -45.5 to -47.5 dB), which is very close to that calculated for juvenile sockeye.

The target was attached to a polyester line (1.0 mm diameter) 2 m above a 2.3-kg weight and lowered parallel to, and at measured distances from, the acoustic axis of the transducer (Fig. 2) to provide estimates of the angle (sine) between the axis and the edge of the beam. Obviously this can only be done while the water surface is calm and no appreciable current is present.

BEAM WIDTH AT DEPTHS GREATER THAN 30 m

In order to permit secure anchoring of the boat during beam width measurements, the initial work was done where water depth was <30 m. To provide an estimate of beam width at greater depths an index of beam width and target depth was prepared by using ping pong balls again as targets. Five targets were suspended at various depths to 58 m on a polyester line which was kept vertical in the water by a weight (2.3 kg) at depth and a float at the surface. The transducer with its axis perpendicular to the water surface was towed past (just brushing) the float at a constant speed. We reasoned that if the FM22 maintained a constant beam angle (i.e. was precisely cone-shaped) over depths to 58 m that the widths of the standard-target traces should increase in direct proportion to depth. This is because stationary targets at

successively greater depths will maintain contact with a cone-shaped acoustic beam for successively longer intervals as the beam approaches, contacts and passes by the line on which they are suspended (Fig. 2). Conversely deviations from a lineal increase in trace width with depth would constitute evidence for a variable acoustic-beam angle and associated irregularities in beam dimensions at depth. The width of each mark elicited by a ping pong ball was measured on the echogram with an ocular micrometer.

When the above measurements were made, no targets were placed below 60 m because we initially assumed that information on EBW below that depth was unlikely to be required to census fish. However, this assumption proved to be wrong as, during surveys at Great Central Lake from December through March, juvenile sockeye were commonly found between 60 and 100 m in the water column at night. To provide an index of EBW at these depths, which exceed the TVG range, we conducted additional observations in which a transect across the lake was replicated at successively lower gain settings and targets were counted for each replicate echogram within the same depth stratum. Stepping down the gain control for each replicate of this transect was analogous to conducting observations with the echo sounder set at the same gain to detect targets of constant size (here a group of young sockeye) distributed at progressively greater depths[4]. The 50-60m stratum was selected for these trials because beam width had been previously determined by us for this depth and concentration of fish appeared to be very stable over the 2-hour interval required for the replicates (Table 1).

CROSS CALIBRATION OF THE FURUNO, FM22 AND THE SIMRAD EY-M

In 1982 we acquired a Simrad EY-M echosounder with the intent of using it interchangeably with the FM22 to census juvenile sockeye in lakes. The Simrad has an operating frequency of 70 kHz, a power output of approximately 75 watts and a pulse width of 0.6 ms. The sounder was equipped with a dry paper recorder, a calibrated output and a 40 log r TVG that operates from 3-60 m with an accuracy of ± 1 dB (Anonymous 1979). System gain can be varied by 9 steps in 3 dB increments. In this study we operated the EY-M at maximum gain which was 3 steps (9 dB) above the lowest setting at which 60 mm juvenile sockeye were detected. The beam-pattern plot of this sounder has been well specified and shows a beam width of 14° at 9 dB above detection limit (Fig. 3). At this level of gain, beam width varies considerably with change in fish size but correction factors can be readily applied as long as fish size is known.

---

[4]The TVG characteristics can not be altered by any adjustable control in this sounder. When the gain control is changed overall system sensitivity is altered but the shape of the TVG curve is not altered.

Acquisition of the Simrad EY-M, designed specifically for quantitative census of limnetic fish populations, provided opportunities not only to determine whether we could use the FM22 and EY-M sounders interchangeably in our survey work but also to conduct an independent assessment of the relative reliability of census results obtained previously with the FM22 operated according to specifications outlined in this paper. Therefore, we have used both the FM22 and EY-M on numerous surveys to obtain data for cross-calibration purposes.

A supplementary check of our beam width measurement procedures described above for the FM22 was conducted by employing the same procedures to measure the beam width of the EY-M in the field. In general the gear deployment, survey, and echogram-processing procedures adopted for comparative surveys were identical to those outlined above with two minor modifications. First, because the operating frequencies of the two sounders differ (200 kHz vs. 70 kHz) both sounders were operated simultaneously on a transect. This was considered to be advantageous as it removed the possibility of ascribing differences in either target numbers or depth distributions recorded with either sounder to spatial or temporal changes in the distribution of the fish. Differences due to the latter feature were possible as the transducers from the two sounders were deployed from different sides of the inflatable boat. However, given the small size of the boat (1.5-m beam), and the beam angles of the sounders (7.6°, 13.3°) it is likely that rather similar "envelopes" of water were insonified by both sounders. The second modification involved the removal from consideration here of any comparative counts from depth-strata in which target overlap precluded reliable visual enumeration (see Hyatt et al. 1984 for details of echogram processing). This situation was infrequent and arose due to the combination of the relatively wide beam angle (13.3°) of the EY-M sounder combined with high density aggregations of sockeye within a depth-stratum on some surveys. Accordingly, 7 depth-stratum counts out of a total of 48 considered below were rejected. Data from eight hydroacoustic and trawl surveys conducted at four lakes during 1985 are presented below either to compare raw target counts or total population estimates based upon echogram recordings from the FM22 and EY-M.

RESULTS

FM22 EFFECTIVE BEAM WIDTH TO 30 m

The depth at which the FM22 first detected the standard target at a given distance from the acoustic axis is shown in Table 2 along with estimates of beam widths. The mean angle between the acoustic axis and the edge of the effective beam (half angle) is 3.8°. However, between 8 m and 16 m the EBW appears to increase from 6.8° to 8° and then remains constant at 8°. This is probably due to some inaccuracy in the TVG at shallow depths where spreading loss of signal strength is very rapid but may result from minor errors in measurement of the distance between the target and the acoustic axis.

FM22 EFFECTIVE BEAM WIDTH BELOW 30 m

Results of the tests conducted to estimate beam width of the FM22 at 30-60 m are shown in Figure 4. The data indicate the effective beam angle is essentially constant through this depth interval. Furthermore, target counts at reduced gain indicate the EBW for juvenile sockeye does not decrease appreciably to a depth of 100 m. When gain was decreased by 11 dB the target count dropped by 3% in the 50-60 m stratum (Table 1). This decrease in sensitivity would also occur if depth was increased by a factor of 1.9 so the equivalent 10-m depth stratum would be approximately 95-105 m. Since the effective beam width apparently decreases by only 3% at 100 m the loss at depths between 50 and 100 m would average somewhat less than 3%.

FM22 VS. EY-M TARGET COUNTS

Comparisons of raw counts generated from visual enumeration of targets within identical depth intervals on FM22 and EY-M echograms indicate that target estimates obtained by the two sounders were well correlated on 6 out of 7 surveys (all r^2 values > 0.82, Fig. 5 a-f). The target detection efficiency of the Simrad EY-M was consistently higher than that of the FM22 with target counts from the former exceeding those from the latter by a factor of roughly 1.2 to 2.6. This difference is not unexpected given the wider beam angle measured by us for the Simrad transducer[5] at maximum gain (13.3°) versus that measured for the FM22 (7.6°). The differences in relative detection efficiency between dates may be attributed to differences in the depth distributions and total target populations defining the relationships between the two sounders.

The weak relationship between target counts derived from the two sounders on the August 18, 1985 survey at Hobiton Lake (r^2 = 0.43, Fig. 5g) is an anomalous result lacking any obvious explanation. One contributing factor may have been a greater dispersion of targets in the water column on this date such that the relationship was defined by lower target densities contributing to lower precision than for most of the other surveys. This suggestion is not entirely satisfactory as the survey conducted at Henderson Lake the previous night exhibits higher precision across a range of target counts no greater than that available from the Hobiton survey (Fig. 5d). An alternate explanation is based upon the observation that none of the Furuno counts from the August 18th Hobiton survey exceeded 100 while counts of up to 300 were derived from the EY-M echogram. This is curious since surveys

---

[5]The 13.3° beam angle measured by us at approximately 9 dB above the detection limit (of a ping-pong ball target) for this sounder agreed very well with the two-way beam pattern plot of this transducer which shows a beam width of 14° at 9 dB above detection limit (Fig. 3).

conducted on dates immediately preceding (Henderson Lake on August 17) as well as following (Sproat Lake September 26) the Hobiton survey suggest the FM22 should have registered higher counts during the Hobiton survey. Thus, it appears that some unknown factor(s) most likely associated with deployment and operation of the FM22 reduced its target detection efficiency during the August 18 survey. This result underscores the importance of maintaining rigorously standardized procedures for both the conduct and quality control of hydroacoustic census work.

Results from comparisons of raw target counts presented above indicate that our modified FM22 sounder and the Simrad EY-M exhibit similar responses to changes in target abundance across a wide range of depth intervals among lakes and survey dates. Further we have ascribed gross differences in the numbers of targets detected by the sounders within a given depth interval principally to the difference between the effective beam angles. All other factors being equal, once we compensate for the difference in beam dimensions, estimates of the total limnetic fish populations derived from surveys using either sounder should be reasonably comparable. Pairwise population estimates based upon simultaneous deployment of both sounders from eight recent surveys appear to support this inference ($r^2 = 0.78$; Fig. 6) and suggest that we may use either the FM22 or the Simrad EY-M as interchangeable instruments for census of limnetic fish populations.

DISCUSSION

Studies conducted by both Thorne (1979) and Nunnallee (1980) have demonstrated that hydroacoustic surveys of limnetic populations of sockeye may be used to generate abundance estimates that are relatively accurate and of known precision. The reliability of abundance estimates, based on the application of hydroacoustic techniques, depends on the certainty with which several parameters can be determined. These include: number of targets detected, effective beam width of the sounder, acoustic transect length and lake surface area.

In our census work measurements of lake surface area and acoustic transect length are generally derived from topographic maps such that errors are unlikely to be large (Rutherford et al. 1986). Field trials documented in the present report were designed to (1.) generate information on the effective beam dimensions of two echosounders when used to census populations of small limnetic fish (2.) determine factors associated with the hardware and procedures adopted for its application that would influence the number of targets detected and (3.) assess the potential for utilizing two different echosounders interchangeably for census of limnetic fish populations. Results presented above have satisfied these objectives and provide the basis for discussion of a number of the advantages and limitations associated with our approach to acoustic surveys.

Our initial selection of the FM22 echosounder to census limnetic fish populations was based principally on considerations which recommended its use for "fly-in" surveys to remote lakes. These included its compact shape, light weight, portability, durability, relatively low cost (<$5000.), narrow beam transducer, its ease of modification to operate off of a 12 volt battery, and the availability of a custom-made TVG circuit. The FM22 was not designed to quantify fish populations on the basis of echo counting or echo integration. Installation of a custom made TVG circuit in the FM22 followed by empirical determinations of its beam configuration with depth (see results) met the minimal requirements for the FM22 to be employed for quantitative assessment of fish abundance by echo counting.

The lack of a suitable interface capable of recording acoustic signals from the FM22 onto magnetic tape dictated that manual processing of echograms from a dry-paper chart recorder be employed to produce raw observations of fish abundance. Since the generation of our numerical data on fish abundance depends on visual processing of paper echograms it has been necessary to adopt procedures which minimize the contribution of acoustic target overlap to echo counting error. Three procedures adopted by us in this regard are (1) execution of acoustic surveys at night during intervals when vertically migrating sockeye and limnetic sticklebacks exhibit maximum dispersion in the top 100 m of the water column (2) utilization of the FM22 with its narrow beam transducer (7.6°) for better target resolution during census of high density populations (>2000 fish.ha^{-1}) of limnetic fish rather than the broader beam EY-M (13.3°) and (3) repetition of surveys for which target concentrations from a given date exhibit too much overlap for reliable counting.

Ehrenberg and Lytle (1972) have provided formulae which predict the fish concentration at which significant overlap may occur for a specified beam width and pulse length. The fish concentrations above which significant (>5%) target overlap may occur, given the pulse length and beam width characteristics of the FM22, have been calculated here for successive depth intervals (Table 3) according to these formulae. During our summer and fall surveys, fish concentrations at depth have not exceeded these critical levels. However, in lakes where sockeye abundance has routinely been greater than 2000.ha^{-1}, critical levels have been exceeded occasionally on surveys during the interval between January and March when the majority of fish have occupied depth intervals below 40 m at night. No estimate of the resultant bias in population estimates obtained under these conditions has been made as yet.

Limnetic fish populations encountered during our surveys of coastal B.C. lakes consist largely of threespine sticklebacks (Gasterosteus aculeatus) and sockeye salmon (O. nerka). Since multiple age groups of both species may occur in the limnetic zone, fish serving as acoustic targets during our surveys may be as small as 25 mm (e.g. sockeye fry, juvenile sticklebacks) or as large as 60 cm (adult sockeye). We routinely operate our echosounders at their maximum gain setting (i.e. maximum signal amplification) to accommodate detection of fish spanning a wide range of sizes. In particular very small fish (25-30 mm) may be underestimated because the reflected acoustic energy decreases rapidly with fish size as does the EBW. Our results suggest that serious underestimation of even the smallest size classes of fish encountered during our surveys is unlikely when the FM22 is operated at maximum gain.

To appraise the potential for decreases in detectibility of fish of different sizes, given use of a constant maximum gain setting, we reinterpret data presented earlier (Table 1) demonstrating the influence of variable gain settings on detection of fish of constant size as follows. Target counts were obtained for sockeye averaging 67 mm fork length from FM22 echograms produced over a short period of time from a single transect surveyed at different gain settings. Of relevance here a 2 step reduction in gain (i.e. from a maximum of gain 10 to gain 8), known to produce an 11 dB reduction in detection sensitivity, produced a 3% reduction in target counts between the respective echograms (Table 1). Now it is possible to calculate how large a change in fish size would be required to produce an equivalent reduction in target counts had it been possible to run the sounder at constant maximum gain while changing the mean size of fish on the transect between repetitive soundings. According to the formula of Love (1971), a 67 mm salmon has a target strength (dorsal maximum) of -48 dB and a reduction of 11 dB in target strength (i.e. the equivalent of a 2 step decrease in gain setting) would require the substitution of fish of 18.5 mm fork length. Thus, all other factors being equal, use of the FM22 operated at maximum gain for acoustic enumeration of two populations of fish averaging 67 mm and 18.5 mm respectively and of identical abundance would result in an approximately 3% bias to underestimate the abundance of the smaller fish. Since we virtually never encounter populations of limnetic fish composed of individuals smaller than 25 mm (Hyatt et al. unpublished data) we conclude that the practice of operating the FM22 sounder at maximum gain produces minimal bias in our population estimates.

The low bias associated with detection of targets varying widely in size and thus in acoustic target strength in our surveys is a consequence of the high level of echosounder gain maintained during surveys. This may be explained through reference to the beam-pattern plots for the types of transducers used during the surveys (Fig. 7). Examination of these plots indicates that at gain settings of only 5-10 dB above detection limit acoustic beam-width changes rapidly i.e. large changes in beam dimensions are induced by relatively small changes in target strength and implicitly in target size. However, at gain settings of 25-30 dB above the limit of detection, EBW remains relatively constant i.e. large changes in target strength (and implicitly size) result in only small changes in beam dimensions. Thus, one of the major advantages of maintaining the FM22 sounder at high gain during execution of our surveys has been the elimination of any requirement to apply correction factors to raw target counts to compensate for changes in the probability of detection associated with changes in fish size, acoustic target strength and sensitivity of the sounder between survey lakes or dates.

By contrast maximum gain on the EY-M sounder is only 9 dB above detection limit for juvenile sockeye. Therefore EBW varies considerably with fish size (Fig. 3) and corrections for changes in sample volume with fish size should be included in calculations of abundance.

Although execution of our hydroacoustic surveys with echosounders maintained at maximum gain is clearly advantageous, we have encountered two situations when this is less than ideal. The first involves comparisons of estimates obtained from winter-spring versus summer-fall surveys when the echosounders have been subjected to major differences in both air and water temperature. We have preliminary observations which suggest that sensitivity

of the FM22 echosounder and transducer may vary with temperature sufficiently to require a one-step gain increase (5.5 dB) in order to detect a standard target in winter (air and water temperature 5°C) as opposed to summer (air and water temperature 15°C). Since this echosounder is operated at maximum gain during virtually all surveys, gain setting increases cannot be used to compensate for this effect. Thus, there may be some tendency for population estimates obtained during the winter-spring interval to be biased downwards relative to estimates completed during the summer-fall interval. Furthermore, cold ambient temperature may affect the time base of the TVG circuit in the FM22. This could have a marked effect on EBW at shallow depths (3-20 m). These phenomena are currently under further investigation (Hyatt et al. in prep.) however since most of our census work has been completed during the summer-fall interval it is not considered to be a major concern.

The second situation in which we have found it inappropriate to conduct surveys at maximum or high gain settings involves census of fish populations where organisms smaller than the fish of interest are also detected. Planktonic larvae of the phantom midge Chaoborus spp. possess a gas-filled hydrostatic organ which makes them readily detectable by high frequency echosounders (Northcote 1964). These larvae are very abundant in three of our survey lakes and are often found at the same depth as juvenile sockeye with the result that, at maximum gain, acoustic targets produced by fish are not separable from those produced by Chaoborus. Given a sounder such as the EY-M in which gain may be adjusted in small increments of 3 dB, it is possible to reduce gain just to the point where very few larvae are detected but most fish are. However, this procedure will often lower system sensitivity enough to produce a reduction in effective beam width which must then be factored into subsequent population estimates. If the resulting sensitivity is low it will also make the EBW very sensitive to changes in parameters such as fish size and ambient temperature. These complications have routinely prevented us from obtaining reliable estimates of limnetic fish populations by echo counting in at least one of our study lakes (Bonilla Lake). Similarly, the presence of many small fish may preclude use of echo counting as described here to assess the abundance of large fish within the same depth stratum of a lake. Echocounting will continue to be of use in these situations only if supplementary sampling gear (e.g. nets, trawls etc.) can be used to establish that vertical segregation of the different classes of targets is well developed enough, over some portion of the diel cycle, to obtain an echogram in which the targets are readily separable for counting.

A number of factors determine that acoustic gear and procedures described in this report are not effective for census of populations of limnetic fish at times when they exhibit pronounced surface orientation (i.e. maintain depths of less than 5 m below the surface). First the transducer mount-depth below the surface and sounder pulse-duration interact to limit the insonifiable region of the water column to depths of > 2 m i.e. the transducer is towed at a depth of 0.5 m and because of pulse length and receiver dead time a fish must be at least 1.5 m below the transducer before it will be detected. Next, given the surface speed of the boat and the pulse frequency of the sounder, the area covered by successive pulses of the echosounder will be less than the area delineated by the beam width and distance travelled at depths less than 5.5 m from the transducer. For example, at a depth of 3 m

when the survey vessel is travelling at 1.5 $m \cdot s^{-1}$ successive sound pulses just overlap and 22% of the area is missed (Fig. 8). Beyond 5 m virtually all the area is covered. Finally, fish within 5 m of the transducer are likely to be influenced by noise from the survey vessel, attempt to avoid it and in so doing may not be detected. Avoidance behaviour elicited by the approach of a large vessel has been observed in some schooling marine fishes (Olsen 1980). However, the degree to which such behaviour occurs in limnetic sockeye or sticklebacks has not been assessed.

For much of the summer and fall underyearling sockeye usually occupy the 5-50 m depth interval at night (Narver 1970, Woodey 1972, Barraclough and Robinson 1972, Goodlad et al. 1974, Nunnallee 1980), therefore, proximity to the transducer is not likely to be a serious problem during surveys to assess sockeye abundance at these times. However, substantial numbers of limnetic sticklebacks commonly occur in the top three meters of water and sockeye in a few lakes occur principally in this stratum (Johnson 1965, Ruggles 1965, Chernoff 1970, Narver 1970). Clearly these fish cannot be accurately assessed by conventional hydroacoustic means alone. Trawl surveys (Johnson 1956; Houser and Netsch 1971; Lewis 1974), a combination of trawling and echosounding (Robinson and Barraclough 1978) or use of upward-looking transducers (Thorne 1983b) may be more appropriate when fish abundance in the top 5 m is to be assessed. Fish that are considerably deeper than 100 m probably cannot be assessed accurately with the equipment and techniques employed here particularly if the fish are small (fork length < 50 mm). However, in the lakes studied to date, the maximum depth at which either juvenile sockeye or limnetic sticklebacks have occurred in significant numbers in the water column has been approximately 100 m. Consequently, the equipment and techniques described here have been adequate for assessment of limnetic fish populations in all but a few study lakes.

In this report we have pointed out the advantages of maintaining echosounders at high gain settings to minimize bias due to sounder instability and variation in fish size. However, we wish to stress here the need for inclusion of a good TVG circuit in any sounder to be used in census of fish populations characterized by wide variations in body size and depth distribution. As a result of two-way spreading loss, acoustic signal strength decreases by 33 dB over a depth range as small as 3-20 m. Unless a TVG circuit within a sounder compensates for this spreading loss, sensitivity and beam width will vary considerably in the upper 20 m of the water column. Most commercial sounders are not equipped with accurate 40 log r TVG circuits. Therefore, one must not assume that the effective beam width of any "off-the-shelf" sounder will be a simple cone or that targets of equal size will be detected at all depths. There is a very real danger of producing grossly inaccurate estimates of fish abundance if echo counting is attempted with a sounder that lacks a good 40 log r TVG.

The equipment and techniques outlined here do not represent the state of the art in hydroacoustic technology as applied to census of fish populations. Considerably more sophisticated systems have been developed for routine applications elsewhere (Johnson and Burczynski 1985; Mitson 1984). However, the hardware and procedures for its use, documented in this report and elsewhere (Hyatt et al. 1984), have a number of advantages. Chief among these are the system's relatively low cost, portability, minimal support

requirements and potential for substitution of a variety of hydroacoustic hardware. The hydroacoustic hardware specified for our surveys, or a suitable equivalent, represents a capital investment of $15,000 or less. All of the gear (including 2 inflatable boats, outboard motors, echosounders, materials and supplies required to set up a field camp for intervals of 2-5 days) used on our surveys is compact enough to be transported to remote sites by single trips with either small aircraft (e.g. a DeHaviland Beaver) or a half ton pickup truck. Although we routinely process echograms after returning to the laboratory and then utilize a series of computer programs to convert raw counts into population estimates, it is quite feasible, if required, to complete echogram counts in the field and to quickly convert these to estimates of population size by using equipment no more sophisticated than a pencil, a ruler and a programmable calculator. Finally, the procedures developed by us for specifying the performance of a non calibrated echosounder (here the Furuno, FM22) will likely suffice to adapt a number of commercially available echosounders for census of limnetic fish populations given modification of the sounders to include a good TVG circuit.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the technical assistance provided by John Candy of McLaren Plansearch Corporation and Dennis Rutherford, DFO Fisheries Research Branch. Kent Wiley of McLaren Plansearch Corporation kindly provided the photograph of the echo sounder and transducer. Sherry Greenham drafted the figures. The text was improved considerably through review by Dr. Robert Kieser.

REFERENCES

Barraclough, W. E. and D. Robinson. 1972. The fertilization of Great Central Lake. III. Effect on juvenile sockeye salmon. U.S. Fish. Wildl. Serv. Fish. Bull. 70: 37-48.

Chernoff, B. W. 1971. Behaviour of underyearling sockeye salmon related to limnetic zooplankton in Qwikeno, British Columbia. Can. Dept. Fish. Forest., Fish. Serv. Pac. Reg. Tech. Rep. 1971-4: 52 p.

Eggers, D. M. 1975. A synthesis of the feeding behaviour and growth of juvenile sockeye salmon in the limnetic environment. Ph.D. Thesis. Univ. Wash., Seattle, Wash. 197 p. + appendix.

Ehrenberg, J. E. and D. W. Lytle. 1972. Acoustic techniques for the estimation of fish abundance. IEEE Trans. Geosci. GE-10: 138-145.

Gjernes, T. W. 1979. A portable midwater trawling system for use in remote lakes. Fish. Mar. Serv. Tech. Rep. 888: 13 p.

Goodlad, J. C., T. W. Gjernes, and E. L. Brannon. 1974. Factors affecting sockeye salmon (Oncorhynchus nerka) growth in four lakes of the Fraser River system. J. Fish. Res. Board. Can. 31: 871-892.

Houser, A. and N. F. Netsch. 1971. Estimates of young-of-year shad production in Beaver Reservoir, p. 359-370. In G. E. Hall [ed.] Reservoir Fisheries and Limnology. Am. Fish. Soc. Spec. Publ. 8, Washington, D.C.

Hyatt, K. D., D. Rutherford, T. Gjernes, P. Rankin, and T. Cone. 1984. Lake Enrichment Program: Juvenile Sockeye Unit Survey Guidelines. Can. MS Rep. Fish. Aquat. Sci. 1796: 84 p.

Hyatt, K. D. and J. G. Stockner. 1985. Responses of sockeye salmon (Oncorhynchus nerka) to fertilization of British Columbia coastal lakes. Can. J. Fish. Aquat. Sci. 42: 320-331.

Johnson, W. E. 1956. On the distribution of young sockeye salmon (Oncorhynchus nerka) in Babine and Nilkitkwa lakes, British Columbia. J. Fish. Res. Board Can. 13: 696-708.

Johnson, R. L. and J. J. Burczynski. 1985. Application of dual-beam acoustic procedures to estimate limnetic juvenile sockeye salmon. Progress Report No. 41. International Pacific Salmon Fisheries Commission, New Westminster, B.C. 33 p.

Kieser, R. and T. J. Mulligan. 1984. Analysis of echo counting data: A model. Can. J. Fish. Aquat. Sci. 41: 451-458.

Lewis, S. L. 1974. Population dynamics of kokanee salmon in Odell Lake. Oregon Wildl. Comm., D.J. Job Prog. Rep., F-71-R-11. 32 p.

Love, R. H. 1971. Dorsal-aspect target strength of an individual fish. J. Acoust. Soc. Am., 49: 816-823.

McCartney, B. S. and A. R. Stubbs. 1971. Measurement of the acoustic target strengths of fish in dorsal aspect, including swimbladder resonance. J. Sound. Vil., 15: 397-420.

Mitson, R. B. (ed.) 1984. Acoustic systems for the assessment of fisheries. FAO Fish. Circ., (778): 132 p.

Narver, D. W. 1970. Diel vertical movements and feeding of underyearling sockeye salmon and the limnetic zooplankton in Babine Lake, British Columbia. J. Fish. Res. Board Can. 27: 281-316.

Northcote, T. G. 1964. Use of a high-frequency echo sounder to record distribution and migration of Chaoborous larvae. Limnol. Oceanog. 9: 87-91.

Nunnallee, E. P. 1974. A hydroacoustic data acquisition and digital analysis system for the assessment of fish stock abundance. Univ. Wash. Sea Grant Publ., (WSG74/2): 48 p.

Nunnallee, E. P. 1980. Application of an empirically scaled digital echo integrator for the assessment of juvenile sockeye salmon (Oncorhynchus nerka Walbaum) populations. Ph.D. Thesis, Univ. Wash., Seattle, Wash. 151 p.

Nunnallee, E. P., N. A. Lemberg and O. A. Mathisen. 1973. Acoustic survey II of Shuswap Lake, British Columbia, Canada. Int. Pac. Salmon Fish. Comm.: 25 p.

Olsen, K. 1980. Echo surveying and fish behaviour. Paper presented to ICES fish capture committee fish reaction working group, Reykjavik, May 1980 20 p.

Robinson D. G. and W. E. Barraclough. 1978. Population estimates of sockeye salmon (Oncorhynchus nerka) in a fertilized oligotrophic lake. J. Fish. Res. Board. Can. 35: 851-860.

Ruggles, C. P. 1965. Juvenile sockeye studies in Owikeno Lake, British Columbia. Can. Fish. Cult. 36: 3-21.

Rutherford, D. T., K. D. Hyatt, J. E. Radziul, and G. J. Steer. 1986. Physical parameters of sockeye salmon (Oncorhynchus nerka) rearing lakes under study by the enhancement assessment unit. Can. MS Rep. Fish. Aquat. Sci. 1878: 114 p.

Stockner, J. G. and K. D. Hyatt. 1984. Lake fertilization: State of the art after 7 years of application. Can. Tech. Rep. Fish. Aquat. Sci. 1324: 33 p.

Thorne, R. E. 1979. Hydroacoustic estimates of adult sockeye salmon (Oncorhynchus nerka) in Lake Washington, 1972-1975. J. Fish. Res. Board Can. 36: 1145-1149.

Thorne, R. E. 1983a. Hydroacoustics, p. 239-259. In L. A. Nielsen and D. L. Johnson [eds.]. Fisheries Techniques. Bethesda, Maryland. Am. Fish. Soc. 469 p.

Thorne, R. E. 1983b. Application of hydroacoustic assessment techniques to three lakes with contrasting fish distributions. In Nakken, O. and S. C. Venema [eds.]. Symposium on fisheries acoustics. Selected papers of the ICES/FAO symposium on fisheries acoustics. Bergen, Norway, 21-24 June 1982. FAO Fish. Rep., (300): 331 p.

Traynor, J. J. and J. E. Ehrenberg. 1979. Evaluation of the dual beam acoustic fish target strength measurement method. J. Fish. Res. Board Can. 36: 1065-1071.

Welsby, V. G. and J. E. Hudson. 1972. Standard small targets for calibrating underwater sonars. J. Sound. Vib. 20: 399-406.

Woodey, J. C. 1972. Distribution, feeding, and growth of juvenile sockeye salmon in Lake Washington. Ph.D. Thesis, Univ. Wash., Seattle, Wash. 174 p. + appendices.

Table 1. Target counts for a transect replicated at different gain settings Great Central Lake Jan. 14/80.

Time PST	Echo sounder Gain	Reduction in Gain (dB)	50-60 m Target counts
19:14-19:32	10	0	355
19:34-19:52	8	11	344
19:58-20:16	6	22	261
20:17-20:34	5	27.5	170
20:35-20:42	4	33	*
20:51-21:05	10	0	352

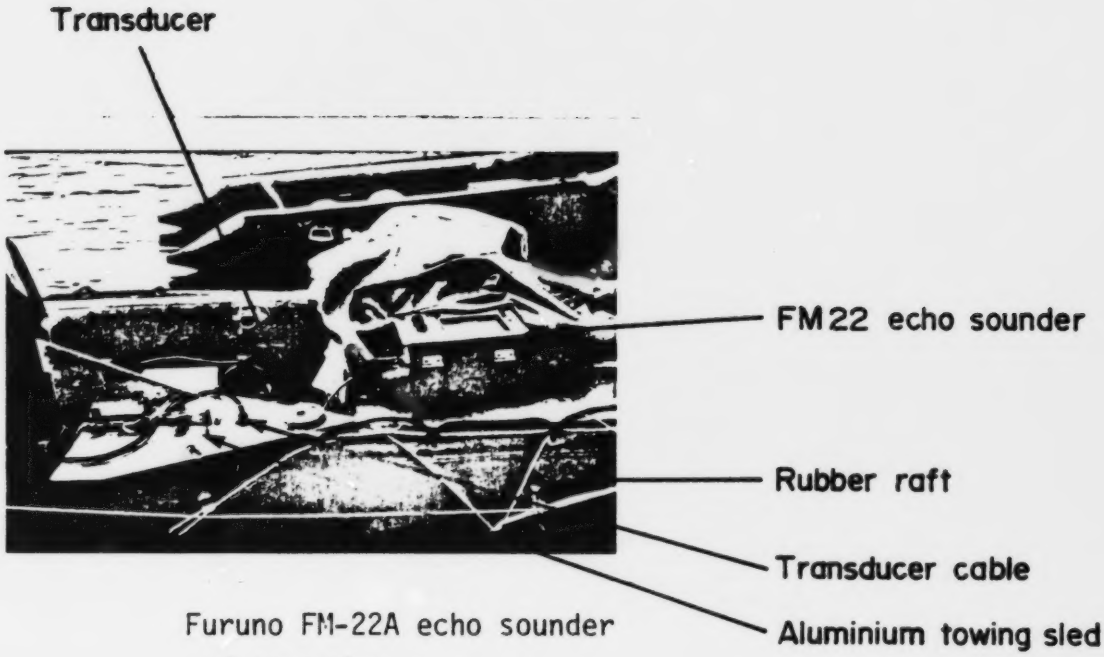
*Approximately half the transect was run at gain 4 and only 17 faint marks were evident at 50-60 m on the echogram. The marks were probably from age 1+ sockeye which were 90-100 mm in fork length and which generally comprise <10% of the juvenile sockeye population present. (Author's unpublished data).

Table 2. Depths at which the FM22 first detected a tournament quality ping pong ball lowered on a line at selected distances from the acoustic axis of the stationary sounder (see Fig. 1) and half beam width (θ) estimates. B_1 and B_2 are points equidistant from the acoustic axis and diametrically opposite each other. Sin θ = $\overline{A/B}$ = 0.067 therefore θ = 3.8° and effective beam width (EBW) = 7.6°.

A	B				
Distance (m) from target to acoustic axis	Depth (m) at which target first shows on echogram				
	B_1	A/B	B_2	A/B	θ°
0.50	8.5	0.059	8.5	0.059	3.4
1.00	16.5	0.061	13.0	0.077	4.0
1.50	22.0	0.068	21.5	0.070	4.0
1.75	25.5	0.069	25.0	0.070	4.0

Table 3. Depth specific fish density calculated to produce significant overlap (>5%) of targets on echograms. Calculations follow the equations of Ehrenberg and Lytle (1972) and assume use of an echosounder with a pulse length of 1.0 ms and an effective beam-width of 8.0°. The model also assumes a random distribution of fish within each 5 m depth stratum.

Depth range (m)	Fish abundance No. ha^{-1}
5-10	15,700
10-15	9,300
15-20	5,500
20-30	5,300
30-40	2,700
40-50	1,800
50-60	1,200



Furuno FM-22A echo sounder and transducer.

Fig. 1. Portable echo sounding equipment: rubber raft, echo sounder and towing sled. The circular echosounder transducer is mounted on the aluminum towing sled.

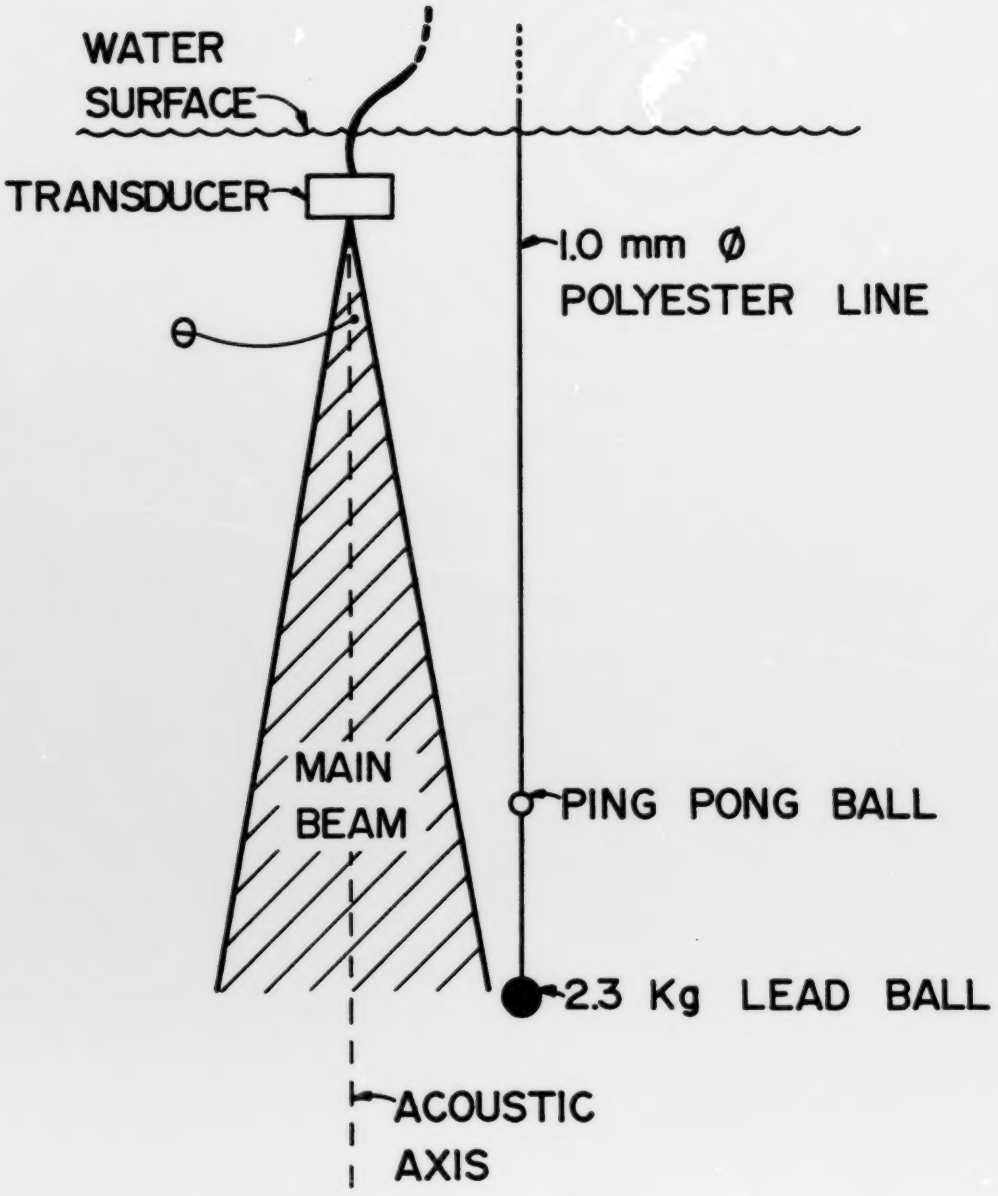


Fig. 2. Diagram of stationary transducer and acoustic beam orientation relative to sounding line with standard target (tournament quality ping pong ball) used to determine the location of the margin of the acoustic beam at various depths. See text for explanation.

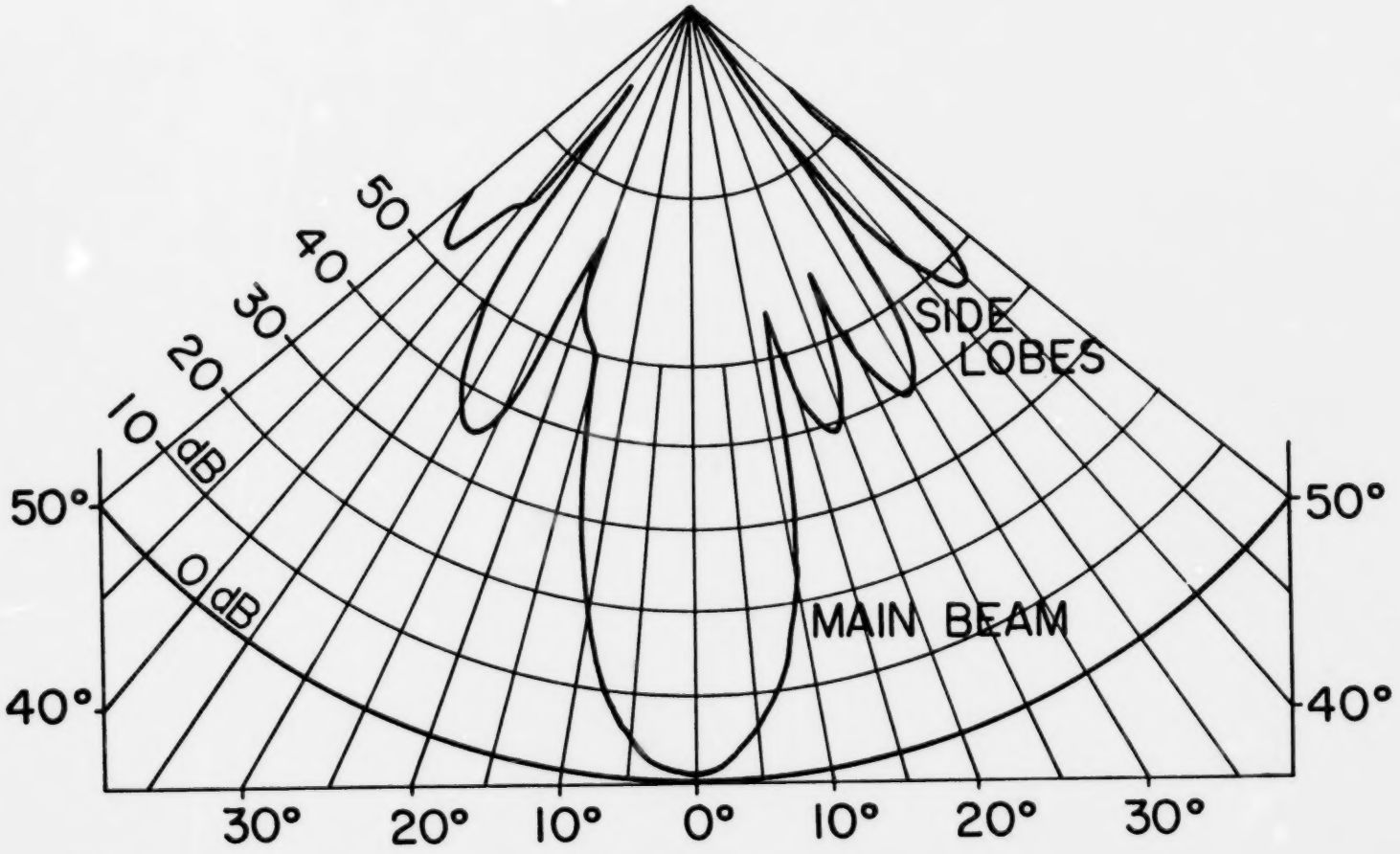


Fig. 3. Two-way beam pattern for the Simrad EY-M transducer.

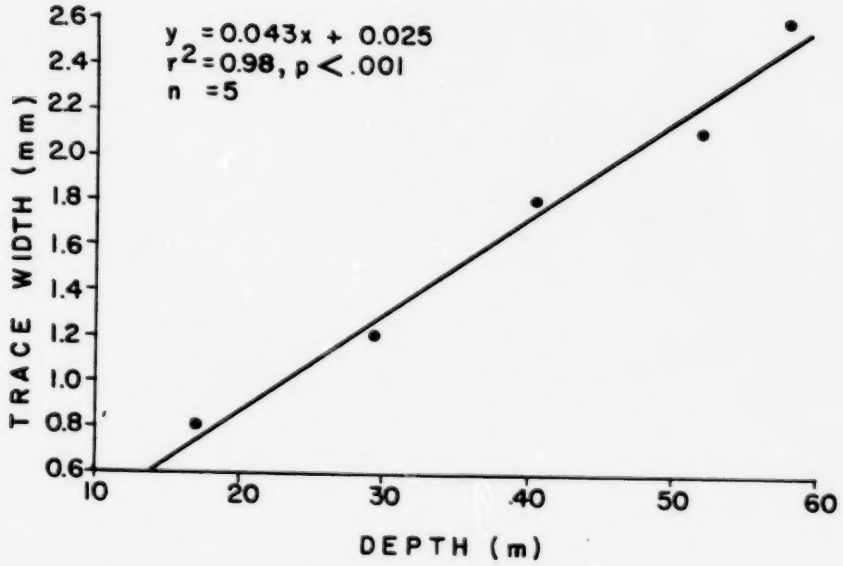


Fig. 4. Relationship between acoustic trace width and water depth for a series of 5 standard targets (tournament quality ping pong balls) maintained in fixed positions at variable depths and subjected to insonification during passes with the FM22 echosounder deployed from an inflatable boat.

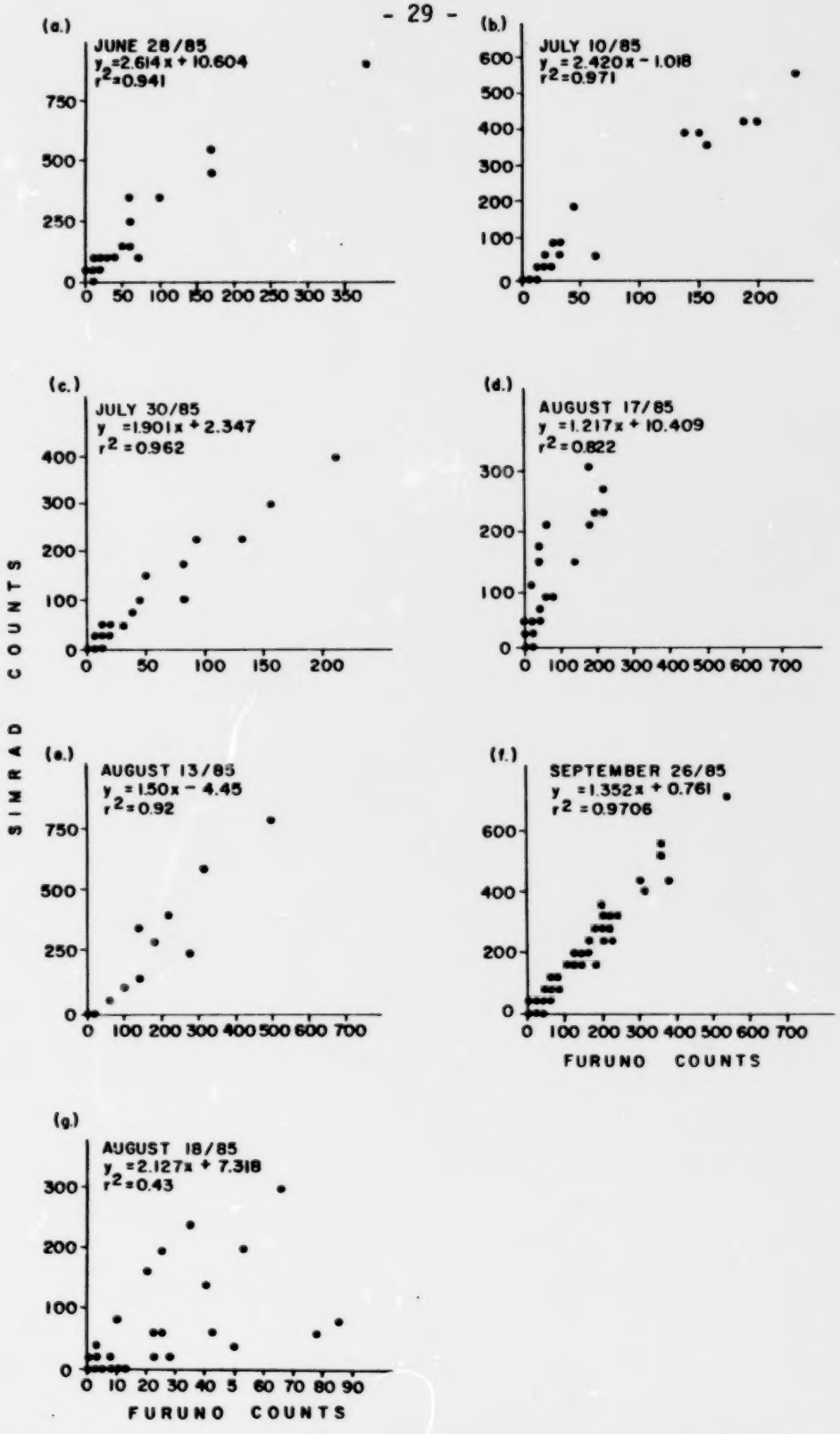


Fig. 5. Relationships between raw target counts obtained from a series of fixed depth intervals on echograms produced through simultaneous operation of the Furuno, FM22 and Simrad EY-M echosounders. Panels a-g indicate results from four lakes on seven survey dates.

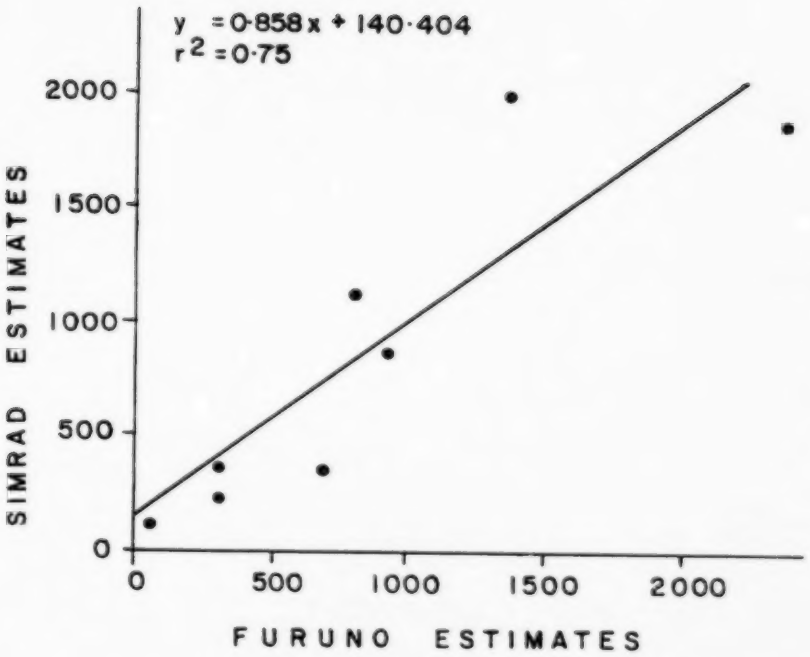


Fig. 6. The relationship between total population estimates of limnetic fish based on target counts obtained from the FM22 versus counts obtained from simultaneous operation of the Simrad EY-M.

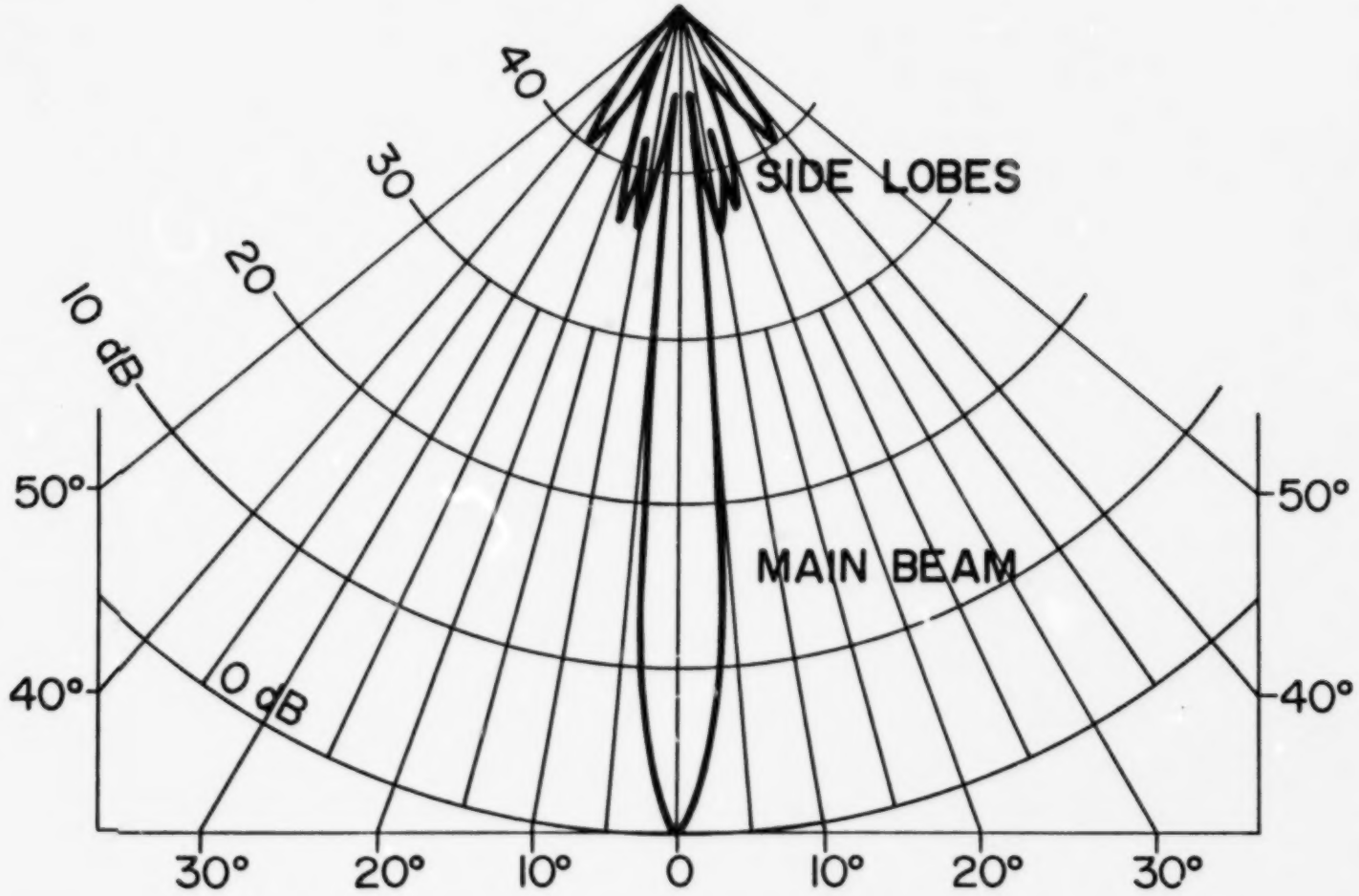


Fig. 7. Two-way beam nattern of a Furuno, model FM22 transducer.

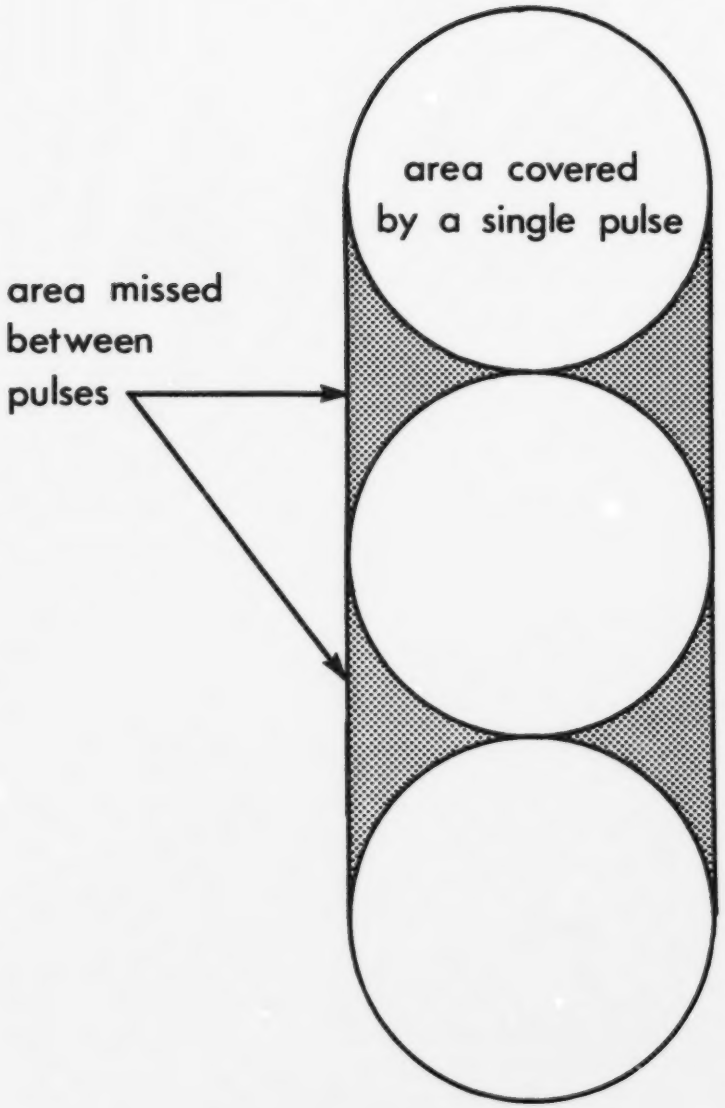


Fig. 8. Acoustic coverage of the horizontal plane at a depth of 3 m by an echosounder with a pulse rate of 3.75 per second and deployed from a boat moving at 1.5 m per second.